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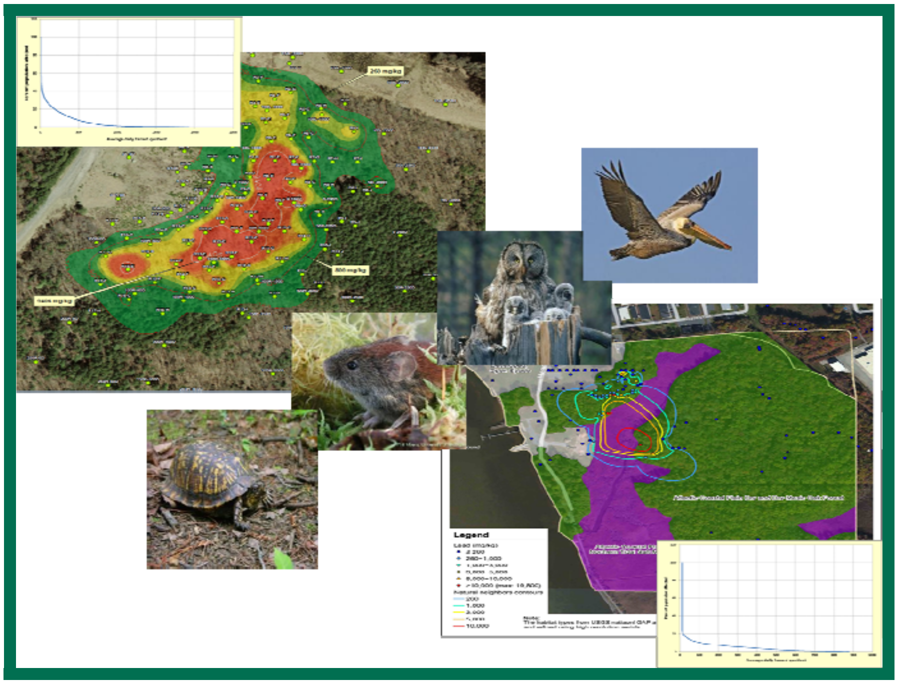

Improvement, Verification, and Refinement of Spatially Explicit Exposure Models in Risk Assessment - SEEM

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14. ABSTRACT
This project was developed to improve direct testing and refinement of the use of spatial models for wildlife exposure assessments. Past studies focused on whether spatial models could improve the assessment of avian exposures to chemicals in the environment. This study examined the value of spatial models with respect to improving the assessment of small mammal exposures in the environment, and aimed to overcome the disconnect that exists when applying 'spatial considerations' between site-wide averages and an assessment that captures exposures based on species-specific habitat preferences. SEEM model outputs were compared to deterministic risk calculations and directly measured blood-lead based risk calculations to determine if SEEM, increased the reliability of exposure assessment. Three sites were selected (two sites in Maryland and one site in California). For small mammals with comparatively small foraging areas, SEEM was no more predictive than site-wide average-based risk calculations. The results emphasized that if habitat is not heterogeneous at ecologically-relevant scales, then SEEM cannot improve risk estimates. Future work will focus on evaluating small mammal exposures where habitat suitability varies over relevant scales. Additionally, SEEM outputs will be evaluated for large mammals and larger foraging areas. Moreover, the larger ESTCP project accomplished the goals of generating greater awareness of the value of spatial models and training risk assessors and managers on using SEEM. The model was also updated in the course of this project.

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Bioaccumulation Model; Spatial Models; Spatially – Explicit Exposure Model (SEEM); Avian Exposures; Environmental Chemicals

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ACRONYMS AND ABBREVIATIONS

APG	Aberdeen Proving Ground
APG-EA	APG Edgewood Area
ARAMS	Adaptive Risk Assessment Modeling System
BAF	bioaccumulation factor
BRAC	Base Realignment and Closure Act
BTAG	Biological Technical Assistance Group
BW	body weight
CFR	Code of Federal Regulations
DoD	Department of Defense
DW	dry weight
EHQ	ecological hazard quotient
ERA	ecological risk assessment
ESTCP	Environmental Security Technology Certification Program
FGGM	Fort George G. Meade
FR	FishRand
GCCIA	Gun Club Creek Investigation Area
GIS	geographical information system
GLP	good laboratory practice
GPC	General Physics Corporation
GPS	Global Positioning System
ha	hectare
HQ	hazard quotient
HSI	Habitat Suitability Index
LOAEL	lowest observed adverse effect level
mg/kg	milligrams per kilogram
NOAEL	no observed adverse effect level
NPL	National Priorities List
PRR	Patuxent Research Refuge
QA	quality assurance
QC	quality control

ACRONYMS AND ABBREVIATIONS (continued)

RI	remedial investigation
SAGA	System for Automated Geoscientific Analyses
SEEM	spatially-explicit exposure model
SETAC	Society of Environmental Toxicology and Chemistry
TSCA	Toxic Substances Control Act
TRV	toxicity reference value
TWEM	Terrestrial Wildlife Exposure Model
UCL	upper confidence limit
USACHPPM	U.S. Army Center for Health Promotion and Preventive Medicine
USEPA	U.S. Environmental Protection Agency
USFWS	U.S. Fish and Wildlife Service
XRF	x-ray fluorescence

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EXECUTIVE SUMMARY

OBJECTIVES OF THE DEMONSTRATION

The project team developed this Environmental Security Technology Certification Program (ESTCP) project to more directly test and refine the use of spatial models for the assessment of wildlife exposures. Past studies focused on whether spatial models can improve the assessment of avian exposures to chemicals in the environment. This study examines the value of spatial models with respect to improving the assessment of small mammal exposures in the environment.

TECHNOLOGY DESCRIPTION

It is recognized that when applying "spatial considerations," a disconnect exists between site wide averages and an assessment that captures exposures based on species-specific habitat preferences. A key aim is to overcome this by applying spatially-explicit exposure models (SEEM). Mistakes might occur by failing to consider properly the spatial aspects of exposure relative to the spatial domain (i.e., the habitat) of the particular population. This study compared SEEM outputs to deterministic risk calculations and directly measured blood-lead based risk calculations to determine if SEEM increased the realism of exposure assessment. The team selected three sites including: The Rod and Gun Club Skeet Range at Aberdeen Proving Ground (APG), Maryland; the Range 17 Trap and Skeet Site (Fort George G. Meade [FGGM] 94, Ft. Meade) at Patuxent Research Refuge in Laurel, Maryland; and 300 Yard Rifle Range, Marin County, California. A direct comparison was made with the APG and Fort Meade sites only.

DEMONSTRATION RESULTS

The results indicated that for small mammals with comparatively small foraging areas, where exposure to habitat does not vary over relevant scales, SEEM is no more predictive than site-wide average-based risk calculations. Although not the expected outcome, the results emphasize that if habitat is not heterogeneous at ecologically-relevant scales, then spatially-explicit exposure models cannot improve risk estimates. Future work will focus on evaluating small mammal exposures where habitat suitability varies over relevant scales. Additionally, SEEM outputs will be evaluated for large mammals and larger foraging areas. The previously conducted avian study emphasized that SEEM is a valuable tool for species with larger foraging ranges, and sites with habitat variability at relevant scales. In addition to completing the demonstration analysis, the larger ESTCP project accomplished the goals of generating greater awareness of the value of spatial models and training risk assessors and managers on using SEEM. The model was also updated in the course of this project.

IMPLEMENTATION ISSUES

In summary, SEEM has been developed to increase the realism of wildlife exposure assessment and to improve the analysis of population risk. In general, "population-level" assessments consider the individuals that comprise the "population" within an area of interest. SEEM tracks exposure of all individuals in a local population, rather than attempting to calculate exposure for a single representative individual.

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1.0 INTRODUCTION

Interactions among biological entities within the environment occur across varying spatial and temporal scales. Likewise, the spatial and temporal distributions of contamination within the environment affect the degree to which plants, animals, and humans are exposed and how they respond. These interactions can be complex. However, using geographical information systems (GIS) and other exposure models that incorporate spatial considerations, risks can be more accurately and realistically estimated. Moreover, visualizing the spatial scales of the risk estimates for wildlife exposures across contaminated sites allows for a clearer understanding of the problem. The present study describes a method to test exposure and risk predictions using a terrestrially-based, spatially-explicit exposure model (SEEM); a parallel report focuses on testing exposure with FishRand (FR)—a model that estimates body burdens of organic compounds in fish. Both models incorporate habitat suitability and contaminant heterogeneity. SEEM results will be compared/corroborated with blood lead concentrations from field exposures, then compared with a blood lead toxicity reference value (TRV) to derive a risk/hazard estimate.

Using ecological hazard quotients (EHQ), SEEM output is compared to both blood lead and deterministic based EHQs. The assumption is that the directly measured blood lead risk measurement is the most realistic of the three approaches and that the deterministic approach is the most conservative. Therefore, the use of SEEM in small mammals is judged to be a success if the EHQ for the SEEM model is 10 times less than the EHQ for the deterministic approach. In other words, SEEM is determined to be successful if its risk estimate tracks the blood lead risk more closely than the deterministic estimate. A ten-fold improvement when comparing model and conventional results to blood lead-based toxicity will be considered successful. The benefits and uncertainties inherent in the different approaches will also be explored.

1.1 BACKGROUND

Environmental risk assessments for fish and wildlife currently use a simplified method to estimate exposure and risk to valued receptor species. This method relies on a site-wide estimate of chemical concentration (e.g., 95% upper confidence limit [UCL] on the average concentration of soil lead) to yield a single, deterministic species-specific estimate of risk (i.e., hazard quotient [HQ]) for each substance of concern. However, chemicals in the environment are rarely distributed in uniform concentrations. Additionally, interactions of wildlife species within the environment occur in biased, heterogeneous ways, often directed by habitat preferences. Similarly, fish may forage selectively in particular habitat areas, or alternatively, may undergo wide migrations that encompass both areas of contamination and “background” areas. Given that chemical distributions are heterogeneous and wildlife exposures are influenced by habitat type and quality, it is apparent that estimates of exposure using a single site-wide soil concentration for each chemical with no consideration of habitat preferences will not accurately capture true exposures on a site. Moreover, the site-wide HQ is not a population metric and has been heavily criticized as being a binary value that provides little information regarding the magnitude of risk. Though the deterministic approach is relatively simple and likely protective from an environmental health perspective, few data have shown it to be reflective of the exposures and associated risks actually experienced by the population at the site.

The disconnect in 'spatial considerations' between the site wide average and an exposure for a habitat limited species is very concerning, particularly when preferences for habitat type are not adequately addressed. By not properly considering the spatial aspects of exposure relative to the spatial domain of the particular population, mistakes can be made. For example, if remediation is the management goal, then it is possible that critical habitat can be destroyed if a site-wide average is used. Spatial models are used to achieve a more refined estimate of exposure that considers the nature of the species as well as the distribution of the contaminant. Generally, a consideration of habitat preferences is absent from ecological risk assessments (ERA), though proposed by many to improve estimating exposure to wildlife (Freshman and Menzie, 1996; Hope, 2000, 2001; Wickwire et al., 2004). In order to provide an option that is straightforward, accessible, and begins to capture habitat and foraging behaviors as influences upon exposure, SEEM was developed. Some advantages of SEEM include increased accuracy and more realistic risk estimates, both of which will improve remedial decision-making. In addition, through iterative application, SEEM provides a valuable tool for data and risk exploration that can create efficiencies in the risk communication and management stages.

1.2 OBJECTIVE OF THE DEMONSTRATION

SEEM has been updated and tested routinely over the past 5 years. In 2006-2007, SEEM was tested on several species of songbirds at two small arms Department of Defense (DoD) sites (Aberdeen Proving Ground [APG], MD and Fort McClellan, AL). The results of SEEM were compared to deterministic methods and with direct field observations with the conclusion that SEEM was more predictive than the deterministic methods (Johnson et al., 2007). To be more widely accepted by the risk assessment community, SEEM needs to be further verified using field results; this is the overall goal of the project. Although SEEM has been used to evaluate avian exposures, it has not been tested with small, less vagile species such as voles, mice, or other small rodents. This demonstration focuses on small mammal exposures to determine if SEEM more accurately predicts risk from lead exposure compared with the single deterministic HQ method. The field validation metric is blood lead concentrations of small mammals captured at the site and compared with a blood lead TRV derived from the literature. Additionally, we were not permitted to collect samples at Fort Baker. Although Fort Baker was initially chosen, this site was later rejected because we could not gain permission from the property owners (the National Park Service) to conduct the field work. Consequently, a direct comparison was made with the APG and Fort Meade sites only.

1.3 REGULATORY DRIVERS

Federal guidance recognizes the need for the assessment of populations of species, assessment of habitats, and the heterogeneity of contamination (U.S. Environmental Protection Agency [USEPA], 1997; 1998). An understanding of how individuals experience contamination in the environment is critical in predictive ERA and is required as outlined in USEPA Guidance (USEPA, 1998). This approach is also consistent with DoD Technical Guidance (U.S. Army Biological Technical Assistance Group [BTAG], 2002a; 2002b; 2005a; 2005b). While spatial models are not specifically required by regulation, their inclusion enables ERAs to be considerably more comprehensive.

2.0 TECHNOLOGY

2.1 TECHNOLOGY DESCRIPTION

SEEM was developed to increase the realism of wildlife exposure assessment and improve the analysis of population risk. SEEM tracks exposure of all individuals[1] in a local population, rather than calculating exposure for a single representative individual. SEEM also increases the realism of the exposure assessment process by incorporating habitat suitability and foraging behaviors at a finer resolution as compared to taking into account the entire site. SEEM is a one-dimensional Monte Carlo model that evaluates variability in exposures to a user-defined group of individuals. It relies on inputs including deterministic bioaccumulation factors, terrestrial food chain ingestion modeling factors, toxicity reference values, habitat suitability, and the selection of one of two options for individual foraging strategies—static and free range foraging. SEEM output is an EHQ (mean and maximum) for each individual for the exposure period; EHQs are then compiled to arrive at a modeled population—effects curve. Figure 1 summarizes the inputs and outputs of SEEM. A detailed description of model functionality is provided in the User's Manual for the Spatially Explicit Exposure Model (Version 4.2, April 18, 2013). The SEEM model is populated through a series of steps—an overview of which is provided in Figure 1.

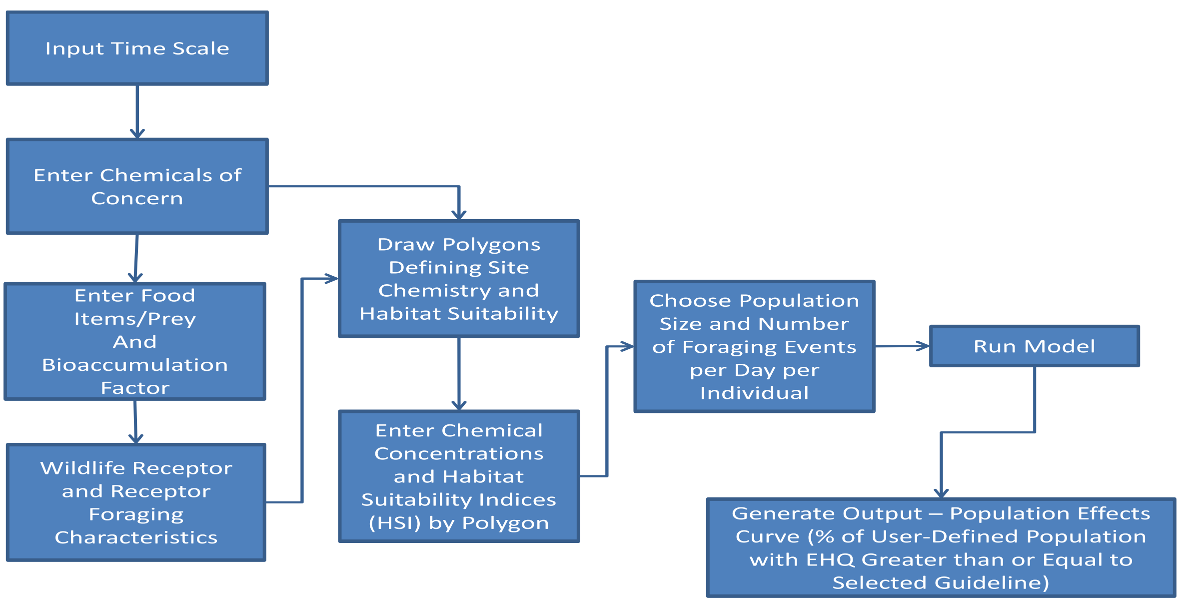

Figure 1. Conceptual overview of SEEM.

2.2 TECHNOLOGY DEVELOPMENT

SEEM was originally conceptualized based on early work by Freshman and Menzie (1996) and Hope (2000; 2001). The U.S. Army funded initial development in 2003-2004, and has continued to add and modify features since its first development through follow-on Army funding. Funding was provided in 2006-2008 to integrate SEEM into the Adaptive Risk Assessment Management

[1] Typically the number of individuals selected is not tuned directly to an observed number of individuals using an area, but rather the number tends to be large to capture representative exposures over time.

System (ARAMS). In 2008-2009, the U.S. Army, with support from the SEEM development team, led an initial comparison of model outputs to risks determined from direct measures in birds. Each iteration focused on developing a more robust internal guidance, improving the efficiency of the underlying programming, and troubleshooting issues identified by reviewers. The current effort has been developed to further validate and fine tune SEEM.

2.3 ADVANTAGES AND LIMITATIONS OF THE TECHNOLOGY

This technology provides a number of analytical advantages. While limitations are present, as they are in any model (as long as they are understood), the context of each user's specific modeling goals can be managed.

The advantages of this technology include:

- Increasing the realism of terrestrial wildlife exposure assessment by incorporating species—specific foraging areas and habitat suitability indices;
- Departing from contamination site area selection as the only spatial context;
- Improving the analysis of population risk;
- Encouraging use through accessible design and user-determined complexity;
- Evaluating life stages and foraging strategies that are the most susceptible and changing remediation plans to meet specific wildlife goals;
- Examining habitat loss tradeoffs—remediating fewer acres of most suitable habitat versus remediating more acreage of less suitable habitat—what combination yields the greatest risk reduction? (Given a fixed foraging size, will the remaining habitat be sufficient to support the local population?); and
- Illustrating the importance of life stage in the risk and remedial decision-making process. By contrast, an individual who might be nesting for example, would forage close to the nest and move comparatively less.

The limitations of this technology include:

- SEEM has value only if the resolution of the foraging receptor and habitat suitability are similar. Modeling exposures of species with comparatively small foraging areas within relatively homogeneous habitat will be no more accurate than the basic site-wide average approach;
- A lack of options to evaluate uncertainty with inputs and outputs;
- Bioaccumulation options/assumptions are simplified;
- The value of the analysis and power are based on the level of effort applied to generating inputs;
- Habitat suitability can be subjective;
- SEEM does not account for dynamic habitats and changes in wildlife usage;

- Foraging strategies are overly simplified and lack important considerations (e.g., limited resource competition, bioenergetics, and inconsistent food access, and
- SEEM is only as good as the inputs and users appreciating the limitations. While no model can account for every dynamic in ecological systems, the assumptions and power of SEEM are summarized in the help materials.

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3.0 PERFORMANCE OBJECTIVES

The effectiveness of SEEM will be determined by its consistency with previous findings and with the similarity of modeled mammal exposures with those that are directly measured. The effectiveness of FR will be evaluated by quantitatively comparing predicted FR fish tissue body burdens between the baseline and spatially-explicit exposure cases, and quantitatively comparing both sets of results to observed tissue concentrations.

Table 1. Evaluation of performance objectives.

Performance Objective	Data Requirements	Success Criteria	Results
Quantitative Performance Objectives			
Further verify the SEEM results by evaluating the model utility for small mammals. NOTE: previous work focused on testing the model with avian species. This project extends that work to small mammals.	Soil lead concentrations, blood lead concentrations in mammals, acid-insoluble ash content of feces (to estimate soil ingestion), location and mapping of nest /burrow/den site location and characteristics.	Consistency of modeled exposure estimates with those directly measured. Although the analysis did not indicate that the model results tracked the directly measured risk estimates, the study emphasized the need to consider the unique characteristics of the target receptor and the habitat under review.	For small mammals, SEEM outputs tracked closely to the deterministic risk estimates, and not the blood lead measurements. This was in contrast to birds because of the small size of the foraging area of small mammals and lack of habitat heterogeneity at the foraging scale. This resulted in consistent small mammal exposure through time and space.
Improve and refine SEEM as a consequence of this effort.	Feedback from peer reviewers and workshop panelists.	Favorable feedback regarding refinements.	The workshops provided an opportunity for experts to discuss the use and value of spatial models. The other workshop focused on instructing new set of users, as well as requesting student feedback. Both workshops yielded valuable feedback and led to program updates and publications focusing on the value and application of spatial models. Many applications of the models were discussed at the workshop (e.g., natural resource damage assessment, and land-use planning). For example, SEEM was used successfully at the Eureka Mills Superfund Site in Utah USFWS, 2009) to estimate ecological risks. The data aligned well with life history attributes, and were used in a weight of evidence approach to characterize risk.

Table 1. Evaluation of performance objectives (continued).

Performance Objective	Data Requirements	Success Criteria	Results
Qualitative Performance Objectives			
Ease of use.	Feedback on usability of the model and time required.	Risk assessors and non-risk assessors will be able to learn to apply SEEM.	The workshop included a diverse group including not only risk assessors, but also many project managers who might not traditionally run exposure models. Feedback was positive at the conclusion of the workshop, from which a consensus was reached on spatially explicit wildlife exposure models and their importance as modeling tools to increase the predictive power of ERAs, as well as to improve the process of arriving at risk management decisions.
Develop a publication from the workshop highlighting current thinking on spatial models in risk assessment – applications, benefits versus risks of using, improvements.	Preparation of the final publication using notes/feedback from workshop participants.	Acceptance for publication in a peer-reviewed journal.	The team published two peer-reviewed articles. Both focused on the benefits of spatially-explicit exposure models and how the models can support a larger set of assessments. In addition, during SETAC 2012, a session was chaired that provided panel talks focused on spatial modeling tools and their advantages.

USFWS = U.S. Fish and Wildlife Service
SETAC = Society of Environmental Toxicology and Chemistry

4.0 SITE DESCRIPTIONS

Two sites were identified for the demonstration of SEEM:

- The Rod and Gun Club Skeet Range in the Gun Club Creek Investigation Area (GCCIA) of the Other Edgewood Areas Study Area within the Edgewood Area National Priorities List (NPL) Site at the U.S. Army Garrison, APG, Maryland; and
- The Range 17 Trap and Skeet Site (Fort George G. Meade [FGGM] 94) located at Patuxent Research Refuge (PRR) in Laurel, Maryland.

4.1 SITE SELECTION

SEEM sites were selected based on the following criteria:

- Well-characterized surface soil data with soil lead concentrations exceeding 10,000 milligrams per kilogram (mg/kg) in screened soil samples;
- Presence of mixed habitat types suitable for rodents and heterogeneous in terms of habitat suitability for target receptors;
- Local or DoD knowledge of wildlife usage;
- Digital maps available; and
- Accessible to the research team.

Having already completed an initial study at two rifle ranges, sustained lead and copper close proximity from spent copper-jacketed lead bullets in the soil accelerated galvanic oxidation that increased both lead solubility, and mobility within the environment.

4.2 THE ROD AND GUN CLUB SKEET RANGE, APG

4.2.1 Site Location and History

The APG GCCIA is located within the Edgewood Area NPL site at the U.S. Army Garrison, APG, Aberdeen, MD. The Chesapeake Bay borders the property. Activities on the site have included testing, research and development, and manufacture of chemical warfare materials (General Physics Corporation [GPC], 2009). The site was listed on the NPL in 1990, and is located east of the demolition debris site. The shot fall zone is to the east of Gun Club Creek marshes (GPC, 2009).

4.2.2 Site Habitat

The Virginia Department of Game and Inland Fisheries has a comprehensive database of wildlife species fact sheets. Although the site of interest is located in Maryland, the Virginia information was helpful in determining species to evaluate. Based on this information, three small mammal receptors were selected in the APG area: the meadow jumping mouse (*Zapus hudsonius americanus*), pine vole (*Microtus pinetorum scalapsoides*), and least shrew (*Cryptotis parva parva*). The habitat suitability for each vegetation type was assigned based on best professional

judgment combined with information provided by the Virginia Department of Game and Inland Fisheries website. Please refer to the Final Report, Section 4, for full details.

4.2.3 Contaminant Distribution

The APG Gun Club lead data came from three different sources:

1. Surface Soil (historical lab) (from 2009 Remedial Investigation [RI] report for Gun Club Creek);
2. X-ray fluorescence (XRF) data (historical lab) (from 2009 RI report for Gun Club Creek); and
3. XRF data (collected August 2011).

The lead concentrations associated with this site ranged from less than 260 to more than 10,000 mg/kg. See the Final Report, Section 4, for the number of samples and concentration ranges.

4.3 THE RANGE 17 TRAP AND SKEET SITE (FGGM 94), PRR, LAUREL, MARYLAND (FGGM)

4.3.1 Site Location and History

FGGM became an active Army installation with an Act of Congress in 1917, and served as an important training location during World Wars I and II, and into the 1960s. In 1988, the facility became subject to the Base Realignment and Closure Act (BRAC), wherein remedial activities were initiated at a number of parcels (U.S. Army, 2010). One of the areas requiring remediation was the PRR North Tract, containing a Trap and Skeet Site (Range 17) for FGGM. Because PRR's mission is to conserve and protect wildlife, an assessment of risk to biota inhabiting the site was necessary, as well as to develop clean up goals. The initial investigation of the Trap and Skeet Site began in 2004 (URS, 2009).

4.3.2 Site Habitat

The Virginia Department of Game and Inland Fisheries has a comprehensive database of wildlife species fact sheets. Although the site of interest is located in Maryland, the information from Virginia is valuable for determining specific species that best represent a mouse, vole and shrew. The habitat suitability for each vegetation type was assigned based on best professional judgment and information provided by the Virginia Department of Game and Inland Fisheries website. Please refer to the Final Report, Section 4, for complete details.

4.3.3 Contaminant Distribution

The soil lead concentrations associated with Fort Meade Range 17 varied from 44 to 130,000 mg/kg. The samples were divided into five separate categories ranked by concentration from the lowest to the highest. The sampling locations are fully illustrated in the Final Report, Section 4.

5.0 STUDY DESIGN

The study is divided into two parts, a field sampling program and an application of SEEM. The goal was to compare the results from directly measured lead concentrations in small mammals to the prediction derived from SEEM runs.

5.1 CONCEPTUAL EXPERIMENTAL DESIGN

SEEM was designed to be a model that improves the prediction of wildlife exposure in the absence of directly measured exposures. As with any model development process, an important step is testing how the model compares with respect to direct measurements. In this case, the direct measurement of wildlife exposure examines blood lead concentrations in small mammals. As wildlife forage across a landscape, they are potentially exposed to chemicals in the soil or food. The SEEM models these exposures and in the process is designed to capture wildlife habitat heterogeneity and preferences more directly than the application of a site-wide exposure statistic. The experiment is designed to compare wildlife habitat heterogeneity and preferences more directly than the application of a site-wide exposure statistic.

5.2 FIELD SAMPLING

5.2.1 Study Sites

5.2.1.1 <u>Fort Meade</u>

The North Tract of PRR, located in Laurel, Maryland, USA (39.08°N, 76.77°W), encompasses approximately 8,100 acres. A part of the area contains soils that are contaminated with lead on an abandoned trap and skeet firing range (Range 17). Range 17 was originally operated by the U.S. Army at Fort Meade but later transferred to PRR through the BRAC of 1990. Lead has been identified as a contaminant of potential concern at the site based on the historical use of lead shot at this range. The refuge is situated in the coastal plain of central Maryland and is characterized by gently sloping terrain, typical of a coastal plain, with elevations ranging from near 80 feet in river bottomlands to about 240 feet at the highest elevations. The predominant soil type is Beltsville silt loam. Land use in the watershed is mainly upland or wetland forests, with significant urban and agricultural development. The general habitat or land cover types for uplands are forest (deciduous, pine, or mixed), oak-pine savannah, shrub-early succession forest, and grassland-old field, whereas habitat types for wetlands are floodplain forest and swamp, river and stream, depressional forest and shrub wetlands, and emergent wetlands. Much of the land is now forested and is a result of gradual reforestation as lands have been retired from agricultural use.

5.2.1.2 <u>Aberdeen Proving Ground</u>

APG Edgewood Area (APG-EA) is an active U.S. Army post located in Aberdeen, Maryland, USA (39.39°N, 76.29°W), and is composed of approximately 13,000 acres. The post operates a regularly used outdoor recreation trap and skeet range (E4737). The facility is in southern Harford County and southeastern Baltimore County, Maryland, on the western shore of the Chesapeake Bay, and is bordered by the bay to the east and south. The area is characterized by a few broad hills with surface elevations up to 35 feet, to low lying areas less than 10 feet. Much of APG-EA

is covered with extensive woodlands and wetlands that provide habitat for many animals, including white tail deer, foxes, and wild turkeys. The area is primarily mixed hardwood forest dominated by oaks, American beech and Virginia pine, and an understory of American holly and sassafras. The habitat is also partly composed of tulip trees, maple, sweet gum, and mowed or developed fields.

5.2.2 Sampling Methods

This study was conducted in compliance with Good Laboratory Practice (GLP) regulations found in the Toxic Substances Control Act (TSCA): 40 Code of Federal Regulations (CFR) 792, plus amendments. For details of sample collection, blood lead analysis, vegetation lead analysis, stomach content analysis, and data analysis, please refer to Section 5 of the Final Report.

5.2.3 Sampling Results

Blood lead concentrations from small mammals collected at Fort Meade and APG as well as capture locations corresponding to trap sites can be found in Tables 5.1 and 5.2, and Figures 5.1 and 5.2, respectively, in the Final Report. Blood lead levels from small tailed shrews (*Blarina brevicauda*) are much higher than those from rodents due to the insectivores being from a higher trophic level. Stomach and vegetation lead concentration results are shown in Tables 5-3 and 5-4, respectively, in the Final Report. A subsample of mammals from each site (goal of two of each gender per species per study site) was euthanized and stomach contents were analyzed for lead concentration. Contents from shrews had higher concentrations of lead than those from rodents due to greater biomagnification of lead in the shrew's prey items than the vegetation that comprised the rodents' diets. Vegetation concentrations come from plant material that was collected at each trap site where a small mammal was captured.

5.3 SEEM MODELING

In addition to the soil chemistry and the habitat suitability data summarized in the Final Report, a number of inputs are required to run SEEM for each species. These inputs include: time scale, chemicals, receptors, food items and ingestion rates, soil ingestion rates, bioaccumulation factors, foraging radius, and toxicity reference values. The selected values for each of these inputs for each study site are presented in the sections that follow.

5.3.1 The Rod and Gun Club Skeet Range at APG, Maryland

A demonstration model was assembled for three small mammalian receptors that represented herbivores, insectivores, or omnivores. Each mammal was assumed to ingest soil contaminated with lead through either incidental soil ingestion with the diet, or by direct contact with the soil while foraging. The model was developed for APG Gun Club, located in Aberdeen, Maryland. The information presented below serves as the input data for the APG SEEM Version 4.2 model, and is intended to accompany the model that was developed.

Time Scale

The default seasons time scale was selected for this model. Therefore, SEEM automatically entered 92 days for winter and 91 days for spring, summer, and autumn. No changes were made to the number of days or seasons.

Chemicals

Lead was the only chemical selected for analysis by SEEM for this model. The CAS# was entered as 7439-92-1.

Receptors

The white-footed mouse (*Peromyscus leucopus*), the short-tailed shrew (*Blarina brevicauda*), and the southern red-backed vole (*Clethrionomys gapperi*) were the three mammalian receptors utilized in these models. The white-footed mouse and short-tailed shrew were both noted during site visits. The southern red-backed vole was assumed to be present because it had previously been noted at the Fort Meade site.

Food Items and Bioaccumulation Factors

The food items included plants, insects, and earthworms. Bioaccumulation factors (BAF) for lead in soil to plants and earthworms as dietary items were selected from U.S. Army Center for Health Promotion and Preventative Medicine (USACHPPM) (2004). The median BAF for soil to earthworms was 3.342 and was selected from Table 4.2 of the Final Report and is equal to 0.388. The BAF for soil to insects was equal to 23.8301 taken from the U.S. Army Terrestrial Wildlife Exposure Model (TWEM) database, as reported in a table entitled "Estimation of Earthworm Body Burdens, BAAP Ecological Risk Assessment, Baraboo, Wisconsin." [Note: the actual U.S. Army TWEM database was not accessible for verification at the time of writing.]
the actual U.S. Army TWEM database was not accessible for verification at the time of writing.]

Foraging Radius

Foraging radius was calculated when representing the home range as a circle and determining the radius. The largest home ranges reported in USEPA (1993) were selected to be conservative. The white-footed mouse home range was 0.059 ha, based on a mean of male and female mice in a mixed deciduous forest in Virginia (Wolff, 1985, as reported in Sample and Suter, 1994). The minimum estimates of the red-backed vole home range vary from 0.5 to 0.07 ha according to a review by McManus (1974); a 0.07 ha home range was selected. The shrew home range was based on an average (0.39 ha) reported for short-tailed shrew in Michigan, Manitoba, and New York (Blair, 1940; Buckner, 1966; Platt, 1976). The home range, reported in hectares, was first converted to units of meters-squared, and then divided by pi. The square root of the radius was calculated to provide input as the foraging radius.

Example calculation: 0.059 ha = [590 m^2 / 3.14] = [187.9 m^2]1/2 = 13.7

Diets

The percentages of food items for each receptor were based on best professional judgment along with information provided in the USEPA, Exposure Factors Handbook (1993). The vole was assumed to be an obligate herbivore, consuming 100% plants. In contrast, the shrew was assumed to be an insectivore, consuming 70% soil insects and 30% earthworms in the diet. The mouse was thought to consume approximately 50% each insect and plant material.

Food and Soil Ingestion Rates

Food ingestion rates were based on allometric equations for food consumption presented in Nagy (1999). Soil ingestion rates used estimates presented by either Beyer et al. (1994) or Sample and Suter (2004). The white-footed mouse (22 g) food consumption rate was based on Green and Millar (1987) and the allometric equation for omnivorous mammals (Nagy et al., 1999). The food ingestion rate (dry weight [DW]) for the white-footed mouse is 3.5 g (DW)/day, or 0.16 kg (DW)/kg (body weight [BW])/day. The soil ingestion rate was approximately 2% of the diet using the rate reported for the white-footed mouse (Beyer et al., 1994). The short-tailed shrew (15 g) food consumption rate for females and males, in New Hampshire, was reported by Schlessinger and Potter (1974) in USEPA. The allometric equation for food consumption in herbivorous mammals (Nagy et al., 1999) calculated the food consumption rate at 2.32 g DW/day or 0.15 kg DW/kg BW/day. Soil ingestion rate was estimated at 13% of the diet, based on Talmage and Walton (1993) and as cited in Sample and Suter (1994).

The red-backed vole food consumption rate was based on the mean minimum BW of 24 g for laboratory voles, according to McManus (1974). Using the allometric equation for food consumption for herbivorous mammals (Nagy et al., 1999), the calculated food consumption rate is 6.19 g DW/day, or 0.25 kg DW/kg BW/day. The soil ingestion rate was estimated at 2.4% of the diet (DW), according to Beyer et al. (1994).

Toxicity Reference Values

The no-observed adverse effects levels (NOAEL) and lowest-observed adverse effects levels (LOAEL) TRVs for mammals were selected from the ecological soil screening level document (USEPA, 2005). The TRV is equal to the highest bounded NOAEL below the lowest bounded LOAEL for reproduction, growth, or survival, and is equal to 4.7 mg lead/kg BW/day. The LOAEL was actually the geometric mean of the NOAEL values for reproduction and growth because it was higher than the lowest bounded LOAEL. The LOAEL was therefore considered to be 40.7 mg lead/kg BW/day.

5.3.2 The Range 17 Trap and Skeet Site (FGGM 94) at PRR, Laurel, Maryland

A demonstration model was assembled for three mammalian receptors that represent herbivores, insectivores, or omnivores. Each mammal was assumed to ingest a portion of soil contaminated with lead either through diet or direct contact with soil during foraging. The model was developed for the Fort Mead Range 17 Trap and Skeet Site, located at PRR in Maryland. The information presented below serves as the input data for the SEEM Version 4.2 model, and is intended to accompany the model that was developed.

Time Scale

The default seasons time scale was selected for this model. Therefore, SEEM automatically entered 92 days for winter and 91 days for spring, summer, and autumn. No changes were made to the number of days or seasons.

Chemicals

Lead was the only chemical selected for analysis by SEEM for this model. The CAS# was entered as 7439-92-1.

Receptors

Three mammalian receptors used in these models were: short-tailed shrew (*Blarina brevicauda*), red-backed vole (*Clethrionomys gapperi*), and white-footed mouse (*Peromyscus leucopus*).

Food Items and Bioaccumulation Factors

The food items included plants, insects, and earthworms. BAFs for lead in soil to plants and earthworms as dietary items were selected from USACHPPM (2004). Please review Section 5 of the Final Report for details of the calculated BAFs for soil to earthworms, soil to insects, and soil to plants.

Foraging Radius

Foraging radius was calculated by identifying the home range as a circle, then determining the radius. The largest home ranges reported by USEPA (1993) were selected to be conservative. The white-footed mouse home range was 0.059 ha, based on a mean of male and female mice in a mixed deciduous forest in Virginia (Wolff, 1985, as reported in Sample, 1994). The minimum estimates of the red-backed vole home range size vary from 0.5 to 0.07 ha according to a review by McManus (1974); a 0.07 ha home ranged was selected. The shrew home range was based on an average home range (0.39 ha) reported for short-tailed shrew in Michigan, Manitoba, and New York (Blair, 1940; Buckner, 1966; Platt, 1976). The home range, reported in hectares, was first converted to units of meters-squared, and then divided by pi. The square root of the radius was calculated to provide input as the foraging radius.

Diets

The percentages of food items for each receptor were based on best professional judgment along with information provided in the USEPA Exposure Factors Handbook (1993). The vole was assumed to be an obligate herbivore, consuming 100% plants. In contrast, the shrew was assumed to be an insectivore, consuming 70% soil insects and 30% earthworms in the diet. The mouse was thought to consume approximately 50% each insect and plant material.

Food and Soil Ingestion Rates

Food ingestion rates were based on allometric equations for food consumption presented in Nagy (1999). Soil ingestion rates used estimates presented by either Beyer et al. (1994) or Sample and

Suter (2004). The white-footed mouse (22 g) food consumption rate was based on Green and Millar (1987) and the allometric equation for omnivorous mammals (Nagy, 1999). The food ingestion rate (DW) for the white-footed mouse is 3.5 g DW/day, or 0.16 kg DW/kg BW/day. The soil ingestion rate was estimated at 2% of the diet using the rate reported for the white-footed mouse (Beyer et al., 1994). The short-tailed shrew (15 g) food consumption rate for females and male shrews in New Hampshire was reported by Schlessinger and Potter (1974). The allometric equation for food consumption in herbivorous mammals (Nagy, 1999) calculated the food consumption rate at 2.32 g DW/d or 0.15 kg DW/kg BW/day. Soil ingestion rate was estimated at 13% of the diet, based on Talmage and Walton (1993), as reported by Sample and Suter (1994). The red-backed vole food consumption rate was based on the mean minimum BW of 24 g for laboratory voles, according to McManus (1974). Using the allometric equation for food consumption for herbivorous mammals (Nagy, 1999), the calculated food consumption rate was 6.19 g DW/d, or 0.25 kg DW/kg BW/d. The soil ingestion rate was estimated at 2.4% of the diet (DW), according to Beyer et al., (1994).

6.0 PERFORMANCE ASSESSMENT

Study performance summaries are provided. Detailed descriptions are found in the Final Report.

6.1 PERFORMANCE OBJECTIVE: FURTHER VERIFY SEEM RESULTS FOR MAMMALIAN AND AVIAN WILDLIFE

6.1.1 Objective

The effectiveness of SEEM will be determined by its consistency with previous findings, and with the similarity of modeled mammal exposures with those that are directly measured.

6.1.2 Data Collection Overview

To evaluate model effectiveness, site-specific data were collected including detailed co-located surface soil lead levels using a Global Positioning System (GPS), species-specific life history details, habitat-specific criteria important in assigning (HSI), and a blood lead toxicity reference value that was derived from the toxicological literature. To run the SEEM model, habitat suitabilities were determined for representative species and demonstration site locations using current GIS maps that were estimated by ecologists working at the sites. In addition, trap site (transects) locations and characteristics were mapped and recorded, and when found, burrow and/or den sites.

6.1.3 Performance Review Based On Success Criteria

Deterministic and SEEM modeled dose risk estimates were compared with blood lead levels in adult and young species. Success was evaluated by determining the similarity of SEEM outputs and estimated risks as compared with direct blood lead exposure assessments. The key goal was to evaluate whether use of SEEM was an improvement over conventional deterministic methods.

For the evaluation, risk is defined as the comparison between predicted body burdens and NOELs or LOELs, where risk is linear with respect to tissue concentrations. Given this assumed linearity, a demonstration of improved agreement between predicted and observed body burdens would improve estimates of “bottom-up” risk. ERAs would also consider additional evidence not evaluated here. An exposure model that closely approximates the risk conclusions reached by direct measurement of body burdens could also provide added flexibility in remedial planning, assessing risk over large areas not amenable to direct measurement, and screening sites early in the assessment process.

While study conclusions did not confirm that SEEM closely tracked directly measured exposures for small mammals, the importance of models that are a good fit is illustrated, as are indicating alternative approaches that might be more appropriate. On reviewing the model outputs, it was noted that small foraging ranges and comparatively homogeneous habitats in small mammals would elicit conclusions similar to a site-wide exposure statistic. Although performance criteria were not met for this objective, it increased understanding of spatial model applicability and permitted improved application in the future. For example, it is expected that SEEM would work well for larger mammals with broader foraging ranges.

6.2 PERFORMANCE OBJECTIVE: IMPROVE AND REFINE SEEM AS A CONSEQUENCE OF THIS EFFORT

6.2.1 Objective

Workshops were conducted to explore broader value of spatial models, and application of the models by the scientific community and regulators. Model improvements were discussed, and addressed four key questions: 1) What are spatially-explicit wildlife exposure models and why are they valuable?; 2) How have the models been applied?; 3) Are there regulatory impediments to their use?; and 4) Are there limitations to the models and can they be improved?

6.2.2 Data Collection Overview

Participants at a workshop held in March 2010 (Menlo Park, CA), evaluated currently available spatially-explicit wildlife exposure models and discussed the use and limitations of SEEM. Suggestions were provided to functionally improve and refine existing SEEM components.

6.2.3 Performance Review Based On Success Criteria

Success of these refinements is determined by feedback with respect to updates and expanded capabilities. During the expert elicitation workshop that was held in March 2010, feedback was offered to guide model refinement. Although spatially-explicit models had found utility in research applications (Loos et al., 2010), a workshop objective was to enhance their use in the regulatory decision-making process. Recommendations were developed to estimate wildlife exposures. Further, their application within the ERA process was a focus of successful initial screening assessments through remediation of contaminated sites. For example, see Section 4.2.3 above for technical descriptions and examples. The workshop enabled a consensus on the importance of spatially explicit wildlife exposure models to strengthen the predictive power of ERAs, and to improve the risk management decision-making process. By enhancing model visibility in both regulatory and risk assessment settings, it was hoped that opportunities would be identified and existing models like SEEM could be more directly focused on end-user's applications and expectations. A separate training course was also held during April 3-4, 2012, in South Falls Church, VA. The project team introduced the model with an interactive question and answer session. Moreover, considerable programming time enabled component upgrades and troubleshooting any program issues after the upgrade. The most noticeable update was inclusion of an Excel tool (SEEM XL), which enabled export of an existing SEEM model file (.MDL) to Excel for an improved quality assurance (QA)/quality control (QC) environment where changes could be made. The tool is described in greater detail in Table 3-2 of the Final Report.

6.3 PERFORMANCE OBJECTIVE: EASE OF USE

6.3.1 Objective

A major goal was to strengthen broad end-user accessibility of SEEM. These models are valued for their power to test theories, identify trends, and run repeatedly under different scenarios.

6.3.2 Data Collection Overview

Comments received during the workshop, and from other users, as well as clarifications in the User Guide were used to increase ease of use.

6.3.3 Performance Review Based On Success Criteria

Both the model and the user's manual were updated. Success of these refinements will be determined by feedback and access of SEEM by risk and non-risk assessors in the future.

6.4 PERFORMANCE OBJECTIVE: DEVELOP A PUBLICATION TO SHARE FINDINGS, MODEL UPDATES, AND CONCLUSIONS REGARDING THE VALUE OF SPATIAL MODELS

6.4.1 Objective

Develop a publication from the workshop emphasizing the current thinking on spatial models in risk assessment – applications, benefits, risks, and improvements.

6.4.2 Data Collection Overview

Preparation of the final publication using notes/feedback from workshop participants.

6.4.3 Performance Review Based On Success Criteria

Performance objective success was peer-reviewed in a publication of model data. Two spatially-explicit exposure model articles were published (i.e., Wickwire et al., 2011; Hope et al., 2011), and Mark Johnson and Ted Wickwire chaired a session at SETAC 2012: "Spatially-Explicit Wildlife Exposure Models: Moving Toward Their Increased Acceptance and Use." Three presentations were given by the project team at SETAC in 2012 (see Section 3.4 of the Final Report).

6.5 PERFORMANCE OBJECTIVE: MANDATORY DELIVERBLES

6.5.1 Objective

Includes documents heretofore not submitted for review that are part of the funding requirement (i.e., Cost and Performance Report and Final Technical Report).

6.5.2 Data Collection Overview

The Cost and Performance Report is an executive summary of findings and the Final Technical Report is an expanded report of methods, background, results, and discussion.

6.5.3 Performance Review Based On Success Criteria

The mandatory deliverables have been completed.

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7.0 COST ASSESSMENT

In this case, the cost assessment focuses on the first performance objective only—"Further Verify the Spatially-explicit Exposure Model (SEEM) Results for Mammalian and Avian Wildlife."

There are two primary components to the cost estimate of the model verification summarized in the previous sections. The components were separated for the sake of clarity. Ultimately, the goal is to identify sites and stages of an assessment during which SEEM might be run to understand wildlife exposure independent of directly measured exposures.

7.1 COST MODEL

7.1.1 SEEM Model Run

A simple cost model for the technology is provided in Table 2. Specific task assumptions are provided in the table, but the general assumptions include:

- Estimates were for a single location and three receptors;
- Inputs were collected from literature sources, electronic databases (maps and some chemistry data) and through hand-entered data tables; and
- The estimated costs did not include field sampling efforts.

Table 2. Cost model for setup and running a SEEM for one demonstration site.

Cost Element	Data Tracked During the Demonstration	Costs	
Site Review	• Document review – locate chemistry data and receptors • Map selection	Project Scientist	12 hrs
	• Select receptors	Project Manager	4 hrs
Assemble Model Inputs – Chemical Data	• Assemble chemistry data – spreadsheet • Quality review of data	Project Scientist	16 hrs
	• Fill data gaps and combine data sets as needed • Review data distributions and select (if needed) geospatial averaging approach	GIS/Statistician (interpolation)	10 hrs
	• Based on geospatial averaging create polygons of chemical concentrations	Project Manager	4 hrs
Assemble Model Inputs – Species Exposure Values	• Review key literature/study sources for species-specific inputs	Project Scientist	14 hrs
	• Preference for field collected or site-specific data	Project Manager	4 hrs
Assemble Model Inputs – Habitat Suitability	• Locate habitat/land cover maps	Project Scientist	14 hrs
	• If pre-identified land cover maps are not available, use remote sensing to delineate habitat types	Project Manager	4 hrs
Insert Model Inputs using Guided Input Steps in SEEM	• Inputs assembled outside of SEEM, then hand entered • Polygons for chemistry and habitat are combined and imported on the image file then traced within SEEM • Habitat suitability indices are assigned to habitat types – in this case based on professional judgment	Project Scientist	10 hrs
Run SEEM	• Model runs are on the order of 2-3 minutes • Report generation can take 5 minutes • Iteration with varying inputs is useful for sensitivity analysis	Project Scientist	5 hrs
			Total Cost: $7,000 - $9,000

7.2 COST DRIVERS

Anticipated cost drivers should be carefully considered when selecting the technology for future implementation.

The SEEM model components that most directly influence the final cost are the inputs. Populating and running the model are not time consuming nor do they require a large investment of money. The inputs are divided into three general categories. Each is briefly described below and the range of effort is introduced.

7.2.1 Chemical Concentrations

When considering the cost unique to SEEM application, it is important to consider the availability of existing chemical data. In some cases, SEEM application will be added to a site assessment after initial analyses have been completed. In this case, there may be a comprehensive chemical data set available and no additional data will be needed. The cost under this example might be the cost to extract the data from an existing database. On the high end of chemical analysis, costs is the case where there are no existing data or the existing data are not reflective of current conditions.

In this case, a full field sampling plan and laboratory assessment will have to be completed with an expense in the thousands of dollars depending on the size of the area and required samples. The most common scenario, however, falls between the extremes with some existing data, but with gaps. For SEEM to be effective the chemical concentrations must cover not only the areas where the release or spill occurred, but also areas where wildlife might forage that may not be impacted by the release. In many cases, the data collected to support SEEM modeling are used for other site assessment activities. At the two demonstration sites described previously, a combination of historic datasets and recently collected XRF data were used in the models.

7.2.2 Habitat Suitability

Habitat suitability is one of the core components of the model. The level of effort and, therefore, cost required to characterize habitat suitability varies from desk-based estimation using widely available aerial and satellite photos and land-use typing by government agencies to a detailed collection of metrics assembled to quantitatively determine the quality of habitat. The most appropriate habitat characterization will depend on the specific project needs and budget. Costs will be highly variable.

On the low end of the range, many aerial photos are available at no cost online so the only expense is for the scientist to review the habitats and assign weights. This can be a step that takes no longer than a few hours. In contrast, attempting to populate a species-specific habitat suitability index with field-collected data can require days or weeks of in-field time spent measuring key metrics. The more common, low-to-moderate cost approach is to begin with available electronic photos and maps and an initial habitat, suitability ranking, followed by an on-the-ground reconnaissance to confirm the ranking assumptions. At the demonstration sites in this study habitat, cover maps were used to rank quality with respect to the type of habitat available and receptor preferences. Some ground-truthing was possible during soil collections.

7.2.3 Bioaccumulation and Ingestion Rates

SEEM is not a bioaccumulation model, but having quality inputs when possible will increase the value of the outputs. In general, bioaccumulation, ingestion rates, and diet composition (including percent soil in diet) are factors that are measurable, but for SEEM this data is usually acquired from literature studies. Therefore, the cost of these inputs is considered to be low. However, if the opportunity presents itself during site work, any directly measured tissue data, ingestion rates, or diet composition data can improve the model.

7.3 COST ANALYSIS

The analysis of the cost of running SEEM on a project begins with a review of the goals of the project. SEEM is a valuable tool for visualizing patterns of exposure on the site, exploring different remedial scenarios with respect to habitat, receptor and chemical interactions, and understanding risk with respect to a group of individuals or a modeled population. Costs will vary depending on who is tasked with assembling the inputs and running the model. The model has been designed with stepwise guidance both within the model and through a companion user manual to facilitate efficient use of the model.

Although not a requirement, it is the team's experience that SEEM is generally used at sites that have some level of completed assessment including chemical screening of the media. There may be gaps that need to be filled, but in most cases, SEEM can be run with a base level of chemical data and access to habitat maps (many available free on state websites).

Users will need to balance model specificity with level of investment available. The model is most often run initially with literature derived input values. However, the model can be made more site-specific by the collection of site-specific ingestion rates, diet composition, and habitat parameters.

In Table 2 (Section 7.1.1), the costs to run SEEM for the demonstration site are summarized along with other details that influence cost. In this section, the cost drivers are discussed along with how data availability affects the overall cost of model application.

With respect to replacing another technology or methodology, SEEM was designed to replace or enhance the traditional use of a non-habitat-specific site-wide statistic for risk estimation. The cost of improving this estimate is the additional data required to characterize the habitat. Most risk assessments include some review of habitat even if the risk calculations do not explicitly consider habitat. SEEM utilizes and enhances data commonly collected for ERAs and remedial studies. In Table 3, a summary of the costs is provided for different levels of effort.

Table 3. Summary of cost ranges for SEEM applications.

Cost Element	Components	Cost Element and Ranking	
Site Review	• Characterize the site based on background documents • Identify key species • Define modeling boundary	Background site studies and maps readily available	Low Cost
		Limited or very old site studies available	High Cost
Assemble Model Inputs – Chemical Data	• Assemble chemical concentration data • This can be a highly variable component depending on data sources • Data may be in electronic table format handed off to the modeler or directly measured field data • In many cases, this involves preparing already electronically obtained data (not collection and analysis of field samples) • Also note that in order to convert point data into polygons some form of interpolation may be completed	Chemical data with limited gaps available electronically – data covers full study area, no spatial averaging needed	Low Cost
		Hard copy chemical data available only – gaps in background areas; basic spatial averaging needed	Moderate Cost
		Limited old chemical data available – field study required; spatial averaging required	High Cost
Assemble Model Inputs – Species Exposure Values	• Inputs include factors such as bioaccumulation factor, ingestion rates, diet items, and percent in diet • In most cases, the inputs are gathered from readily available literature sources • Exposure inputs measured directly are preferred, but higher costs are incurred (e.g., diet composition, percent soil in the diet)	Literature derived inputs	Low Cost
		Field study determined inputs	High Cost
Assemble Model Inputs – Habitat Suitability	• This component consists of identifying habitat/cover/land-use types and then ranking the suitability with respect to use by each of the selected receptors • This is another input that can be highly variable depending on the source – direct versus indirect observation • A direct field assessment of the habitat might vary from a qualitative report back from a field crew collecting samples, to a formal quantitative habitat assessment • Indirect field assessments use the power of satellite and aerial imagery and remote sensing expertise (e.g., combined with a state agency's GIS land use maps) • Generally users locate digital maps and satellite/aerial photography for no cost	Remote sensing habitat survey – not field visit	Low Cost
		Qualitative – direct observation of habitat paired with remote maps	Moderate Cost
		Detailed quantitative habitat survey – measured metrics	High Cost
Insert Model Inputs Using Guided Input Steps in SEEM	• The one time-consuming part of data entry is drawing the polygons in the polygon tool. Future versions will allow for direct import of shape files. This step takes 80% of the effort in this step • SEEM XL create review efficiencies	<5 total chemical and habitat polygons	Low Cost
		>5 total chemical and habitat polygons	High Cost
Run SEEM	• The time required to run the model will depend on the number of individuals selected in the model population • Model runs must be completed independently for each receptor • It is important to organize the outputs and name the output files clearly to avoid future confusion • Iterative runs can be made for sensitivity testing • Since all data have already been entered, this step has a low time/cost	Run model (final cost depends on number of iterations)	Low Cost

8.0 IMPLEMENTATION ISSUES

Based on numerous workshops, the feedback has been positive regarding the accessibility and utility of SEEM, but implementation challenges remain. Some challenges include:

- Continued hesitation to use SEEM model results in site assessment reports;
- Continued hesitation by regulatory and scientific community to make final decisions based on the result outputs;
- Lack of regular incremental model improvements and updates due to shortage of maintenance funding;
- Tracking programming software updates through time and fixing bugs that result from software upgrades in custom models; and
- Missing linkage to GIS software and issues installing the software on machines with specific

These issues have been managed in the following ways:

- As part of this project, an expert conference was held to discuss ways to encourage greater application of spatial models in regular practice. Two publications were generated (Hope et al., 2011; Wickwire et al., 2011), and a session was presented at the SETAC 2012 annual meeting, that focused on the power and value of these models.
- SEEM has been moved to a more modern platform and the programming notation was updated and clarified. Though the change to a new programmer required a background review of an individual outside the project, the result was a more flexible and accessible platform. Response time for reports of computer challenges has been reduced.
- Finally, development has started for a SEEM tool to be integrated into a freely available GIS platform. This effort was outside of the scope of this project; therefore, it is not ready for wide distribution, but based on input from the programmer it was evident that the next incremental update must include GIS. This step will greatly increase the flexibility of future updates. A brief introduction to SEEM-GIS is provided below. SEEM-GIS is a complete implementation of animal movement and exposure algorithms as a plugin for the free, open-source GIS software System for Automated Geoscientific Analyses (SAGA). Users simply prepare two raster grids of the same dimensions in their GIS software of choice, with cell values representing chemical concentrations and habitat suitability. Grids may be arbitrarily sized and are not restricted to the 25 x 25 cells used by standalone SEEM following interpolation of polygons. SAGA can easily import all common raster file formats, and users enter the simulation parameters for SEEM in an easy-to-use settings dialog with context-sensitive help for parameters. After the simulation is complete, SEEM-GIS provides a table of statistics by individual receptor, and a variety of visualization and export options for the simulated foraging positions. The SEEM algorithm has been rewritten in cross-platform C++ for speed, accuracy, and ease of integration in other GIS frameworks such as ArcGIS and Quantum GIS. Simulation results have been validated against the existing algorithms used in standalone SEEM.

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APPENDIX A

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